Potential modifications to the IPHC harvest policy

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Abstract

Potential modifications to the current IPHC harvest policy are presented. The first modification is to suspend application of the "Slow Up Fast Down" quota adjustment to the annual Fishery Constant Exploitation Yield in determining Staff Recommendations for commercial Catch Limits. The second modification concerns how bycatch and wastage mortality of halibut less than 32 inches in length is accounted for in halibut management. Current policy accounts for this source of mortality through harvest rate adjustment. Options to account for bycatch and wastage mortality less than 32 inches directly, as deductions to Total Constant Exploitation Yield, are analyzed and discussed. The intent of these options is to provide alternatives that achieve the same stock conservation objectives as the existing harvest policy.

Introduction

The current IPHC harvest policy was developed during the 2000s and has remained essentially unchanged for the past five years. The policy is described in detail in several documents (e.g., Clark and Hare 2006, Hare and Clark 2008). The fundamental characteristics of the policy are as follows:

- At its core, the policy has a target harvest rate on the exploitable biomass, which is defined by commercial selectivity at length. The target harvest rate was established through simulation modeling of a halibut fishery and a range of life history processes including alternating high and low recruitment regimes and density dependent growth. The choice of harvest rate represents a precautionary balance between catch and spawning biomass preservation. The current target harvest rate of 0.20 results in a reduction of Spawning Biomass per Recruit (SBR) to 32% of that estimated for the unfished state. In areas of particular concern, the target harvest rate has been lowered to 15% representing extra caution.
- Threshold and limit reference points are established for the female spawning biomass, which is defined by the maturity schedule. The target harvest rate is scaled downward from 0.20 when the spawning biomass reaches the threshold and goes to zero at the limit. The threshold is defined as 30% of unfished spawning biomass and the limit is 20% of unfished spawning biomass. Unfished spawning biomass is computed as spawning biomass per recruit in the absence of fishing times estimated average recruitment in an unproductive regime. These calculations are done on a coastwide scale.
- A "Slow Up Fast Down" (SUFD) annual commercial catch quota adjustment is employed to limit annual variance in quotas due to both biological and methodological changes. SUFD is applied on an area by area basis. The SUFD limits commercial catch increases to 33% of the increase between the previous year's adopted Catch Limit (CL) and the Fishery Constant Exploitation Yield (FCEY); catch decreases are limited to 50% of the computed change from the previous year's adopted CL and the following year's FCEY. Note that in Areas 2A and

2B, the SUFD is applied to the combined sport and commercial catches (subsistence is also included in 2A).

- Halibut bycatch and wastage mortality (BAWM) under 32 inches in length (U32) is not counted directly as part of the "other removals" (i.e., non-commercial catches) when determining commercial catch quota. The effect of the U32 BAWM is accounted for in the harvest rate simulations as "missing" recruitment, which has the effect of lowering overall productivity and reducing the harvest rate at which spawning biomass approaches the threshold and limit reference points.

The purpose of this document is to examine the rationale for using, and the consequences of changing, the SUFD adjustment and the current method of accounting for U32 BAWM.

Slow Up Fast Down catch quota adjustment

The SUFD catch quota adjustment has been utilized since 2001. Implementation of the SUFD adjustment was essentially a formalization of a process the Commission had often used at the Annual Meetings to arrive at each year's commercial CL. The rationale was that many factors could influence annual estimates of biomass and sustainable catch but, due to the relatively widespread age structure of halibut, true annual variations were likely to be not as large as the estimates. Thus, changes in available catches were generally phased in over time and a working procedure was developed such that decreases were phased in more rapidly than increases. Specifically, if a reduction in available catch was recommended, 50% of the reduction was implemented whereas if an increase was recommended, only 33% of the increase was implemented. While many agencies around the world employ a similar process of graduated changes in catch limits or realized harvest rates among years (e.g., the European Union Common Fisheries Policy has a tiered system of allowable changes in Catch Limits, based on knowledge of the stock; permissible changes range from 15-25%), the IPHC employs asymmetric control rules for changes in catch limits among years.

The SUFD quota adjustment was not always recommended by staff but in general it was more often applied than not. Following the 2006 Center for Independent Expert review (Francis 2007, Medley 2007), the SUFD adjustment was formally investigated as part of the harvest policy and became official IPHC policy (Hare and Clark 2008). Over the past few years, however, as biomass declines have persisted, there has been a growing concern among staff about continued use and application of the SUFD adjustment because some of the conditions the stock is currently experiencing were not included in the original evaluation of the SUFD.

In the simulations that supported the SUFD quota adjustment it was found that, over the long term, SUFD was more precautionary than a harvest strategy without the adjustment. In other words, average spawning biomass was slightly higher and removals slightly lower with the adjustment (Hare and Clark 2008). This can be anticipated from the asymmetrical nature of the adjustment; more catch is "surrendered" during times of yield increases than is taken during periods of yield declines. However, this net benefit is only realized over the long term, which would include periods of both biomass and yield increase and decrease. During the period of time during which the SUFD has been in effect, there has been only a steady decline in biomass. A biomass decline occurs when removals exceed surplus production. In addition, we have transitioned between closed-area, area-specific stock assessments to a single coastwide assessment with partitioning of biomass. This change was motivated by the recent PIT program results that indicated that halibut migration is an ongoing process even on the exploitable component of the stocks. Under this new information, closed-area assessments were shown to be in error and some areas sustained, at least for a number of years, realized harvest rates well in excess of the target harvest rate. Thus, there has been for a number of years the need to further reduce removals. Table 1 provides a summary of the effect of applying the SUFD adjustment over the past four years. The table lists both the FCEY, which is computed by multiplying the target harvest rate by the exploitable biomass and subtracting Other Removals (not including U32 BAWM), and the SUFD adjustment applied to the FCEY. This illustrates that SUFD has had the effect of increasing commercial catches much more often than decreasing catches over the past four years. Further, the SUFD adjustment has become so engrained that the public tends to focus solely on the SUFD-generated recommended catch levels and not on the FCEY-generated levels. In essence, the (higher) SUFD adjusted values have become the baseline against which the final commercial CLs are often evaluated. Table 1 also lists the final CLs for each of the past four years as percentages of the FCEY values. In recent years the final Catch Limits have been within 0.5-1.0 million pounds (1-2%) of the sum of the individual regulatory area SUFD catch limit recommendations. However, those values were already 4-5 million pounds greater than the FCEY values. Although this overall departure could be argued to be relative small at the coastwide scale, it is crucial to point out that the SUFD adjustment is not applied coastwide but on an area by area basis, where departures between the adopted CL and the FCEY have been much larger for some areas (e.g. 41%-103% in 2A, 35%-94% in 2B, 58%-84% in 2C, see Table 1). Therefore, the realized harvest rates have consistently been in excess of the target harvest rate for some areas.

There is an additional argument against continued present use of the SUFD adjustment. In the simulations that supported the SUFD, halibut size-at-age was held constant over time. It is an ongoing concern, however, that size at age has continued to decline. The following example is intended to illustrate the effect of declining growth rates on a harvest policy employing the SUFD adjustment. It attempts to mimic, in the simplest manner possible, halibut biomass dynamics and fishery impacts as presently understood. Consider a very basic model of halibut dynamics:

$$B_{t+1} = B_t + R_t + G_t - M_t - C_t$$

where B is biomass, R is recruitment, G is growth, M is natural mortality, and C is catch. In a population at equilibrium, increases in biomass (i.e., recruitment and growth) are balanced by decreases to biomass (i.e., natural mortality and catch). For this example, we will model all four processes as rates, related to biomass. Recruitment and growth each annually add 20% and 15%, respectively, of the previous year's biomass to the next year's biomass. Natural mortality removes 15% of the annual biomass and fishing is set at a rate of 20% (i.e., the harvest rate is 0.20) of the previous year's biomass. If the initial biomass is 100 units, then this is a system at equilibrium:

$$B_{t+1} = 100 + 20 + 15 - 15 - 20 = 100$$

This is illustrated in Figure 1a by the horizontal trajectories for both biomass and catch. We consider next what happens when growth rates begin to decline. For this example, we will assume an annual decrease in growth rate of 5%. Thus, in the first year, biomass increase due to growth is .95*15% of biomass in the previous year. In the second year, biomass increases due to growth would be $.95^2$*15% of biomass in the previous year, and so on. Recruitment adds 20%, while natural mortality and catch remove 15% and 20%, of the previous year's biomass, respectively. Figure 1a illustrates how catches and biomass vary both without (labeled "with FCEY catches") and with a SUFD (labeled "with SUFD catches") adjustment to catch levels under conditions of declining growth rates. This short analysis illustrates that as biomass begins to decline following a decrease in growth rates, the decline in biomass is greater with a SUFD adjustment to catch levels as compared to the simple FCEY catch levels. The accompanying Catch plot shows that the SUFD adjusted catch levels are always above the FCEY catch levels thus harvest rates greater than 0.20 persist and are never brought down to the 0.20 level.

The difference in catches and biomass are measurable but relatively small in this particular example. The situation is somewhat akin to that in Area 3A where harvest rates are approximately equal to the target harvest rate during this period of growth decline. However, in several areas, notably Area 2, we are transitioning from a higher-than-target harvest rate situation (in excess of 0.30) and the effect of the SUFD is considerably more pronounced (Figure 1b). In this situation, we begin from a state in which F (Fishing Mortality) is taking 30% of the exploitable biomass and the goal is to decrease catches so the fishing mortality rate is 0.20. Under a FCEY policy, the reduction in catches is immediate and the level of biomass decline is moderate. However, with a SUFD adjustment, catches remain quite high and the biomass decline is considerably steeper. After a few years the SUFD catches are not much greater than the FCEY catches, assuming no departures between SUFD adjusted catches and adopted CL, but the impact on the biomass was immediate and cumulative. Departures from the SUFD would magnify this impact.

Finally, we note that this example is not intended to be exhaustive. We did not consider a myriad of more complex situations such as variable recruitment regimes nor did we attempt to model age specific growth responses as was done in the original harvest policy evaluation. Our concern was to demonstrate how a general decline in biomass, such as one resulting from decreasing growth rates, would affect application of the SUFD and the results have shown that as long as biomass declines, catches will be greater than the target rate and biomass declines exaggerated. It is important to note that this argument was developed on the basis of declining growth rates such as we have observed in the halibut stock in recent years. However, any combination of factors - resulting from biological or management processes - that causes removals to be consistently greater than surplus production (hence causing an uninterrupted decline in biomass) would show the same effect. We conclude with a note that this is not an argument for permanent suspension of the SUFD adjustment. For example, in an environment of increasing growth rates, the SUFD adjustment works to increase biomass more rapidly than non-application of the adjustment and would be highly desirable as a means of rapidly building biomass. This situation is illustrated in Figure 1c. We should also consider modification to the SUFD policy in future years to minimize the problem of persistent periods of unidirectional trends in factors affecting biomass. For example, a policy of Slow Up – Full Down, wherein management consistently took the full decrease recommended by the FCEY, would achieve such a goal.

Accounting for bycatch and wastage mortality in the harvest policy

The bycatch of halibut in non-directed fisheries has long been a contentious issue. Estimation of bycatch dates back to the 1960s while accounting for the effects of bycatch in the management of the halibut resource dates back to the 1970s. Generally speaking, "accounting" refers to the action of "compensating" the halibut stock for the effects of bycatch removals. The bycatch mortality distribution differs markedly from the directed fisheries mortality distribution (Fig. 2) and this has greatly complicated overall management of the halibut resource. The full history of bycatch compensation/accounting measures will not be recounted here but is detailed in several IPHC-authored papers and documents (Sullivan et al. 1994, Clark et al. 1997, Clark and Hare 1998, Clark and Hare 2006). Quantifying and accounting for wastage is a relatively recent addition to halibut management, beginning around 2000. In practice, it has generally been added to bycatch and treated similarly.

The present method of accounting for bycatch has been in place since 1997. The major features are as follows:

- Bycatch (and wastage) mortality at length is assembled for all regulatory areas
- Mortality of fish larger than 32 inches is subtracted from the Total CEY in the area where the mortality occurred because its effect is the same as a commercial removal.
- Mortality of fish smaller than 32 inches is accounted for in the harvest policy simulations.

At the time this methodology was established, modeling work had taken place which showed that most bycatch had primarily local impacts (Clark and Hare 1998). Attempting to determine a "downstream" compensation scheme where CEY reductions were made for young halibut caught "upstream" was deemed quantitatively complex, highly dependent upon poorly known migration rates, and politically contentious. Incorporating the effect of juvenile bycatch into the harvest policy, by harvest rate adjustment, provided a means of accounting for the effects in a simple and straightforward manner while still protecting the stock (Clark et al. 1997).

Over the past 15 years, an increasingly large proportion of total removals have been accounted for by sport and subsistence fisheries. The size distribution of these two fisheries tends to be characterized by larger halibut than those taken as bycatch but smaller than in the commercial catch (Fig. 2). The sport and subsistence removals have been treated the same as commercial removals because simulation modeling showed that the effect on overall yield tended be roughly the same for these fisheries (Hare and Clark 2007). Bycatch (and under 32 inch wastage), with its smaller size distribution, had a much greater effect on overall lost yield. However, the differential treatment of sport/subsistence catch vs. bycatch and wastage continues to cause confusion and dissatisfaction among some constituency, particularly in the size ranges where there is overlap (i.e., 26 to 32 inches).

For the remainder of this document, the following acronyms will be used.

- BAWM: bycatch and wastage mortality
- U32: halibut under 32 inches in length
- U32/O26: halibut under 32, but over, 26 inches in length
- U26: halibut under 26 inches in length
- SBR: Spawning Biomass per Recruit, which is the total weight of mature female halibut remaining in the ocean under different levels of fishing, *at equilibrium conditions*, divided by the average number of halibut recruits. This is typically scaled as a percent of SBR under conditions of no fishing and no loss of recruitment.

In general terms, the effect of accounting for U32 BAWM in the harvest policy is to end up with a target harvest rate less than would occur if there was no BAWM. The target harvest rate is one that reduces spawning biomass to a designated level. For the Pacific halibut harvest policy, the simulations are quite complex and the selected target harvest rate of 0.20 was deemed optimal given factors such as recruitment losses to bycatch, variable growth rates, variable recruitment regimes, etc. The purpose of this analysis is to consider different means of accounting for BAWM within the harvest policy. A full blown re-evaluation of the harvest policy, in a Management Strategy Evaluation framework, is currently under development but it is still at least a year away from completion. In the interim, a simpler method of analysis based on SBR is developed here to consider alternatives. SBR approaches are common for Alaska and Pacific groundfish harvest policy analyses (Clark 1991, Quinn and Deriso 1999). In the SBR analysis described below, a harvest rate of 0.20 reduces SBR to a level that is 32% of the estimated level in the absence of fishing.

Methods

For this simplified analysis, a deterministic (i.e., non-stochastic) SBR model is used. The first step is to compute SBR in an unfished state. This value of "pristine state" SBR is then used as the metric against which the various scenarios are evaluated. Five scenarios are explored.

1. Fished state, with no bycatch. All removals are commercial catch.
2. Fished state, bycatch assumed to reduce recruitment by 10%, all other removals are commercial catch.
3. Fished state, U32 BAWM assumed to reduce recruitment by 10%, removals are in the ratio of 78% commercial (includes O32 wastage), 16% sport/subsistence, 6% O32 bycatch. This represents the current fishery and harvest policy.
4. Fished state, U26 BAWM assumed to reduce recruitment by 5%, removals are in the ratio of 73% commercial, 15% sport/subsistence, 12% O26 bycatch and U32/O26 wastage). This relates to a harvest policy where BAWM in the 26-32 inch range is deducted as a direct removal and not included in the harvest rate.
5. Fished state, no reduction in recruitment due to BAWM. Removals are in the ratio of 70% commercial, 14% sport/subsistence, 16% bycatch (all sizes and U32 wastage). This relates to a harvest policy where all bycatch and wastage are deducted as direct removals and none is factored into the harvest rate.

Scenario 1 and Scenario 2 are provided to illustrate the impact of factoring bycatch alone into the harvest rate. Scenario 3, which most closely mimics current harvest policy, establishes the baseline management level of SBR, relative to unfished, at the current target harvest rate of 0.20. In evaluating Scenarios 4 and 5, the goal of the analysis is to determine what harvest rate in those scenarios will have the same impact on SBR as occurs in Scenario 3 baseline. For all five scenarios, we can also examine the tradeoff between direct removals and the reduction in SBR.

For Scenarios 3, 4, and 5, the definition of exploitable biomass, for the purpose of defining harvest rate and total catch, remains the same, i.e., it is the commercial selectivity at length schedule applied to the population. This allows the use of a consistent definition of fishable biomass among the scenarios even as it is recognized the size distribution of catches will differ according to the mix of fisheries. However, the existence of a size limit for the commercial fishery but not for other direct removals does not permit a joint definition of exploitable biomass for all fisheries. In the deterministic calculations, the removals are governed by the fishery-specific fixed selectivities-at-length (Fig. 3a). The sport/subsistence selectivity schedule is assumed to follow the setline survey selectivity schedule. Previous analyses have demonstrated that the size composition of the survey catch is very similar to the sport size composition (Clark and Hare 2006). The bycatch selectivity is less well known, but the same as that employed in the stock assessment is used here. With these two other selectivities, an equivalent exploitable biomass can be calculated, along with the fishery specific harvest rate, that results in the assigned level of catch, determined by the harvest rate and fixed scenario-specific fishery percentages listed above, for the sport/subsistence and bycatch fisheries. The ratio of the three fisheries (commercial, sport/subsistence, bycatch) for the scenarios reflect actual average catches over the past three years, and are summarized in Table 2.

A further clarification on the need for fixed ratios among the different fisheries is in order. Within the simulations, total removals are determined by the harvest rate multiplied by the commercial EBio. The actual quantity and size distribution of the removals are governed by the ratio among the fisheries, exactly as occurs in present day halibut management. As an example, the 2010 TCEY was 26.19 M lbs in 3A. Other Removals were 4.87 M lbs for sport/subsistence and 1.92 for O32 bycatch. Ignoring the SUFD adjustment, if the remaining available catch after subtraction for Other Removals was entirely allocated to the commercial CL, the ratio among the three fisheries would have been 74% commercial, 19% sport, 7% O32 bycatch. Thus, given the actual removals in Table 2, fixed ratios among the fisheries - which differ by scenario - can be computed such that the correct size distributions and quantities are removed from the population in the simulations.

The main operational equations are as follows:

Unfished state

1. $N_{1,s} = 0.75 * \bar{R}_{1995-2004,s} N_{1,s} = 0.75 * \bar{R}_{1995-2004,s}$
2. $N_{a+1,s} = N_{a,s} e^{-M} N_{a+1,s} = N_{a,s} e^{-M}$
3. $a_{max} = 50 a_{max} = 50$
4. $SBio = \sum_{a=1}^{a_{max}} N_{a,s=f} * w_{a,s=f} * Mat_{a,s=f}$

   $SBio = \sum_{a=1}^{a_{max}} N_{a,s=f} * w_{a,s=f} * Mat_{a,s=f}$
5. $SBR = \frac{SBio}{N_{1,s=f}} SBR = \frac{SBio}{N_{1,s=f}}$

Scenario 1.

Equations 1, 3, 4, 5 apply

6. $EBio = \sum_{a,s} N_{a,s} * w_{a,s} * sel_{a,s} EBio = \sum_{a,s} N_{a,s} * w_{a,s} * sel_{a,s}$
7. $C_{a,s} = HR * N_{a,s} * w_{a,s} * sel_{a,s} C_{a,s} = HR * N_{a,s} * w_{a,s} * sel_{a,s}$
8. $N_{a+1,s} = \left(N_{a,s} * e^{-M/2} - C_{a,s}\right) * e^{-M/2}$

   $N_{a+1,s} = \left(N_{a,s} * e^{-M/2} - C_{a,s}\right) * e^{-M/2}$

Scenario 2.

Equations 2-8 apply

9. $N_{1,s} = 0.9 * 0.75 * \bar{R}_{1995-2004,s} N_{1,s} = 0.9 * 0.75 * \bar{R}_{1995-2004,s}$

Scenario 3.

Equations 2-5, 8, 9 apply

10. $EBio_{fishery} = \sum_{a,s} N_{a,s} * w_{a,s} * sel_{a,s,fishery}$

    $EBio_{fishery} = \sum_{a,s} N_{a,s} * w_{a,s} * sel_{a,s,fishery}$
11. $Catch_{total} = HR * EBio_{commercial} Catch_{total} = HR * EBio_{commercial}$

12. $Catch_{sp} = 0.16 * Catch_{total} Catch_{sp} = 0.16 * Catch_{total}$

13. $Catch_{by} = 0.06 * Catch_{total} Catch_{by} = 0.06 * Catch_{total}$

14. $Catch_{comm} = 0.78 * Catch_{total} Catch_{comm} = 0.78 * Catch_{total}$

15. $HR_{fishery} = \frac{Catch_{fishery}}{EBio_{fishery}} HR_{fishery} = \frac{Catch_{fishery}}{EBio_{fishery}}$

16. $C_{a,s,fishery} = HR_{fishery} * N_{a,s} * w_{a,s} * sel_{a,s,fishery}$

$C_{a,s,fishery} = HR_{fishery} * N_{a,s} * w_{a,s} * sel_{a,s,fishery}$

17. $C_{a,s} = \sum_{a,s,fishery} C_{a,s,fishery} C_{a,s} = \sum_{a,s,fishery} C_{a,s,fishery}$

Scenario 4.

Equations 2-5, 8, 10-11, 15-17 apply

18. $N_{1,s} = 0.95 * 0.75 * \bar{R}_{1995-2004,s} N_{1,s} = 0.95 * 0.75 * \bar{R}_{1995-2004,s}$

19. $Catch_{sp} = 0.15 * Catch_{total} Catch_{sp} = 0.15 * Catch_{total}$

20. $Catch_{by} = 0.12 * Catch_{total} Catch_{by} = 0.12 * Catch_{total}$

21. $Catch_{comm} = 0.73 * Catch_{total} Catch_{comm} = 0.73 * Catch_{total}$

Scenario 5.

Equations 1-5, 8, 10-11, 15-17 apply

22. $Catch_{sp} = 0.14 * Catch_{total} Catch_{sp} = 0.14 * Catch_{total}$

23. $Catch_{by} = 0.16 * Catch_{total} Catch_{by} = 0.16 * Catch_{total}$

24. $Catch_{comm} = 0.70 * Catch_{total} Catch_{comm} = 0.70 * Catch_{total}$

where *N* is numbers, *a* is age, *s* is sex, *f* is female, *R* is recruitment at age 1 estimated from the coastwide stock assessment, maximum age is 50 with no plus group, *Mat* is maturity, *w* is weight, *SBio* is spawning biomass, *EBio* is exploitable biomass, *C* is catch, *HR* is harvest rate, *sel* is selectivity, *fishery* is commercial (*comm*), sport/subsistence (*sp*), or bycatch (*by*).

This model allows one to compute SBR as a function of harvest rate and consider the impacts of BAWM. We use recruitment at age 1, instead of age 6 or 8, as often referred in the stock assessment, to facilitate comparison with the next set of models that directly deduct BAWM catches including at young ages. Since this model has only natural mortality prior to commercial catch, a 10% reduction applied at age-1 is almost exactly the same as a 10% reduction applied at ages 6 or 8. A value of 75% of recent recruitment is used to represent recruitment across both productive and unproductive regimes; we are currently in a productive regime where recruitment is approximately twice recruitment in an unproductive regime (Clark and Hare 2002). The weight-at-age schedules represent the average over the past three years and are kept constant in all years and in all scenarios. Survey weight-at-age is used to represent weight of fish in the ocean as well as all non-commercial catches. Commercial weight-at-age is used for commercial catches and to compute EBio. The resultant selectivities-at-age are illustrated in Figure 3b. Commercial selectivity is length-based and based on estimates from the halibut stock assessment.

Scenario 4 differs from Scenario 3 in that U32/O26 BAWM is counted as part of removals and not factored into the harvest rate. The number of halibut killed as bycatch or wastage in the

26 to 32 inch range accounts for around 30% of the total under 32 inches. However, as the U32/O26 fish are older, there would be less natural mortality on these fish prior to recruitment than would occur for the U26 fish. A rough calculation puts lost recruitment at about 50% for each size category. Thus, Scenario 4 uses a 5% reduction in recruitment to account for U26 BAWM while accounting for U32/O26 BAWM as removals/catch. Scenario 5 differs in that all U32 BAWM is counted as part of the direct removals and are not factored into the harvest rate. It should also be noted that U26 wastage is miniscule, accounting for less than 0.25% of total removals. It is being lumped together with U26 bycatch for accounting and completion purposes but it has essentially zero impact on any of the results.

Results

To succinctly illustrate the tradeoff between catch and reduction in SBR with increasing harvest rate, a phase plane diagram plotting a curve for each scenario is illustrated in Figure 4. For each scenario, the curve begins in the upper left corner at a harvest rate of 0. For the scenarios with no reduction for bycatch (Scenarios 1 and 5), SBR is 100, i.e., the SBR for a pristine population in the absence of fishing. For the scenarios with a reduction in recruitment, the SBR at a harvest rate of 0 is either 90% (Scenarios 2 and 3) or 95% (Scenario 4). As harvest rate is increased, the SBR drops and average catch increases. Catch is the total sum of the different fisheries and does not include any component (such as U26 bycatch or O26/U32 BAWM) that is being accounted for by reduced recruitment. This is a subtle, but key, distinction to be kept in mind. Depending on the scenario, U32 BAWM is sometimes counted as a direct removal and sometimes not. For instance, the current situation (modeled as Scenario 3) does not count U32 BAWM as a direct removal. In the simulations, this U32 BAWM is removed from the population as missing recruitment. As Figure 4 summarizes a great deal of information, several comments are in order.

- The direct effect on both productivity as well as SBR is illustrated by the differing curves for Scenarios 1 and 2. Bycatch, in the form of reduced recruitment and lost catch to the non-bycatch fisheries, provides less catch and greater SBR reduction at all harvest levels. Thus, under the current method of dealing with bycatch, incorporation of bycatch as lost productivity results in a lower harvest rate than would be the case in the absence of bycatch.
- Comparison of Scenarios 2 and 3 illustrates the slightly different effect of removals being 100% commercial (i.e., Scenario 2) as opposed to the present-day actual mix of removals (i.e., Scenario 3). At any given harvest rate, the average catch is almost the same, however the rate of SBR decline is greater for Scenario 3. This reflects the size distribution of the removals and is related to the larger catch of females in the non-commercial fisheries at small sizes when growth potential is greater than mortality.
- Scenario 3, as noted, best reflects current harvest policy as well as halibut harvest. U32 BAWM is not counted as direct removal in quota setting (hence, not counted as catch in the simulations) and the mix of fisheries is 78% commercial, 16% sport/subsistence and 6% O32 bycatch. The target harvest rate, based on much more involved dynamic simulations, is set at 0.20 (0.15 in areas of concern, for precautionary purposes). A harvest rate of 0.20 in this scenario reduces SBR to 32% of unfished SBR (thin horizontal line in Figure 4). **Any change to the harvest policy should have an equal or lesser impact on SBR**. Adoption of the management practices associated with Scenarios 4 or 5, is based on adopting the scenario-relevant harvest rate that reduces SBR to no lower than 32% of unfished. That is, we wish

to maintain the same stock conservation objective with any alteration of the current harvest policy.

- Scenario 4 would move U32/O26 BAWM from incorporation in the harvest rate calculation to being counted and charged as an "other removal" (in management) and as catch (in the simulations). Recruitment is reduced by 5% in the SBR calculations. The scenario average catch/SBR curve is shifted vertically from that for Scenario 3. Any given harvest rate results in a larger catch than Scenario 3, but this is due to the inclusion of U32/O26 fish to the catch category. SBR is reduced to 32% at a harvest rate of around .215, higher than the Scenario 3 harvest rate.
- Scenario 5 takes Scenario 4 one step further and treats all direct removals as catches and no BAWM is subtracted as recruitment. Unfished SBR starts higher and EBio and catches are greater yet than Scenario 4, again because of how the U26 BAWM is totaled. The harvest rate that reduces SBR to 32% in this scenario is 0.230.

A summary of the harvest rates, and average catch, that would reduce SBR to 32% of unfished is listed in Table 6. Perhaps the key feature of this table is the difference in average catch between Scenario 3 (current management practice) and Scenarios 4 and 5. Scenario 4 average catch is a bit more than 5 million pounds greater than Scenario 3. However, Scenario 4 counts as catch all U32/O26 BAWM. The average actual U32/O26 BAWM for 2007 to 2009 was 5.119 million pounds. Scenario 5 total average catch was another 7 million pounds higher; actual U26 BAWM for 2007-2009 was 4.12 million pounds. The amount of commercial catch (including O32 wastage) differs little among Scenarios 3, 4 and 5). It is important to note there is no expectation for the simulated and actual values to perfectly align. The simulations are scaled directly by the recruitment values. It is, however, reassuring that these results indicate that Scenarios 4 and 5, which more directly subtract removals as opposed to Scenario 3 which accounts for them in harvest rate adjustment, provide very similar results in terms of overall catch. This reinforces staff's previous contention that there are multiple methods for "dealing" with bycatch. The most appropriate method at any given time is a function of data, scientific knowledge, and management considerations. Changing from one method to another however, inevitably results in changes in available quotas among regulatory areas.

Discussion

This re-analysis of the harvest policy has thus far focused on the coastwide stock without consideration for individual regulatory areas. In a sense, this is just an extension of application of the current harvest policy which was developed via simulation modeling of the "core areas" (2B, 2C, 3A) and then applied to the other areas (Clark and Hare 2006). One of the central tenets of IPHC area-specific management is to set harvest such that a fish has the same probability of fishing mortality no matter where it is located. Scenarios 4 and 5 were developed to provide the Commission with an alternative to how U32 BAWM is handled in overall halibut management. However, the scenarios are based on the coastwide stock and catch limit recommendations are area-specific. As such, to implement either Scenario 4 or 5, requires a decision to be made as to **where** the new subtractions to available catch are taken. To inform that discussion, the following points are considered germane.

- Smaller and younger halibut migrate more extensively than larger and older halibut. The cumulative, over the lifespan loss, of spawning potential, due to bycatch and wastage of smaller fish (e.g., U26) differs from that of larger fish (e.g., U32/O26 and larger). Therefore, compensating locally for BAWM of very small fish does not place the compensation in the area where the loss will actually occur.
- Simulation modeling has shown that the effect of lost yield and spawning potential due to U32 wastage, with its larger size distribution, is much more local than is the case with U32 bycatch (Valero and Hare 2010).
- Historically, setline catch quota reductions for bycatch have been distributed in various ways. This includes reductions in proportion to estimated biomass distribution - at a time when all bycatch was accounted for in this fashion - to the current situation where O32 bycatch is deducted locally and the remainder is factored into the harvest rate calculation.
- The actual effect of accounting for U32 bycatch in the harvest rate calculation is to effectively distribute the effect in proportion to EBio distribution. This occurs because the simulations result in a target coastwide harvest rate and when that lower (due to reduced recruitment) rate is applied to all areas. The areas with the most biomass have the largest catch quota reductions. It should be noted that the present EBio distribution reflects harvest practices over the past several decades and the unfished EBio distribution would likely differ. Migration modeling suggests that EBio would have a more eastern and southern distribution than at present (Valero and Hare 2010). However, the estimate of unfished EBio distribution is highly dependent on imprecise migration rates whereas the actual, present-time, EBio distribution is known relatively precisely. Basing estimates of U32 BAWM on current EBio distribution, while perhaps understating the eastern and southern impacts, is more reflective of actual impacts than using the location where the BAWM occurs.

Scenario 4 presents a simpler, and perhaps less contentious, situation than Scenario 5. As sport and subsistence catches, both of which have substantial O26/U32 components, are subtracted locally, it would be both logical and consistent to treat O26/U32 BAWM similarly. For Scenario 5, O26/U32 BAW would logically also be subtracted locally but the U26 component could be handled either of two ways: subtracted locally (hereafter termed Scenario 5a) or distributed in proportion to EBio (hereafter Scenario 5b).

Scenario 5a, with all U32 BAWM subtracted locally, would impose a heavy loss to commercial quotas entirely in the area where the BAWM occur. It would also place all spawning biomass compensation in the local area even though most of the impact on spawning biomass of U26 fish is downstream (Valero and Hare 2010). Scenario 5b hearkens back to how bycatch was handled when compensation was first introduced, though at that time it also included the O32 component. Scenario 5b recognizes that the bycatch mortality impact is on areas far removed from the source of mortality and it is in the areas where the losses occur that compensation should be taken. As a final note, distributing the impact of the U26 BAWM in proportion to EBio is computationally similar to the present situation where the harvest rate is adjusted downwards in all areas to compensate for the loss of recruitment.

Before presenting a comparison of the alternative methodologies applied to last year's assessment output, one other important detail remains to be discussed. The SBR analysis presented above used a target SBR of 32% of the unfished level (associated with a harvest rate of 0.20 in Scenario 3, the current situation) to determine what harvest rate would result from achieving the target SBR in the other Scenarios. At present time, IPHC regulatory areas 2A, 2B, 2C and 3A have a target harvest rate of 0.20. Thus, for Scenarios 4 and 5, the calculations for these areas will use the identified target harvest rates of 0.215 (for Scenario 4) and 0.230 (for Scenario 5). However, regulatory areas 3B, and all of Area 4 use a lower target harvest rate of 0.15. A number of studies over the past several years (e.g., Hare 2005, Hare 2006, Hare 2010) have identified a need for further precaution in these "areas of particular concern". These areas have a present target harvest rate of 0.15. To maintain the same relative level of target harvest rate between the eastern areas (3A and east) and western areas (3B and west), the Scenario 4 and Scenario 5 target harvest rates are scaled upwards by the ratio of the new/old rates in the east. Thus, in the western areas, the revised target harvest rates are 0.161 (Scenario 4, computed as 0.215/0.200 * 0.150) and 0.173 (Scenario 5, computed as 0.230/0.200 * 0.150).

The following table present the 2010 Exploitable Biomass (EBio, in M lbs), target harvest rates (HR, as fraction of EBio), Total Constant Exploitation Yield (TCEY, in M lbs), Other Removals (OR, in M lbs), and Fishery Constant Exploitation Yields (FCEY, in M lbs). This table was provided in the 2010 Annual Meeting Bluebook (page 138). Note that there was an error in the original version of the table in the Bluebook (the entry for Area 4CDE OR) and the corrected version is available online at the IPHC web page. Tables after this reference table present the values that correspond to Scenarios 4, 5a, and 5b in generating equivalent regulatory area FCEYs. The SUFD catch adjustments that were employed to arrive at staff catch limit recommendations are not included here - these tables compare only the current method of FCEY derivation with the alternative methods of accounting for U32 BAWM.

2010 Fishery Constant Exploitation Yield calculation. This is Scenario 3 in the SBR analysis.

	2A	2B	2C	3A	3B	4A	4B	4CDE	CW
EBio	4.094	30.382	25.101	130.962	65.723	21.673	19.858	36.207	334.000
HR	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	0.179
TCEY	0.819	6.076	5.020	26.192	9.859	3.251	2.979	5.431	59.627
OR	0.246	0.522	2.63	7.913	0.95	1.131	0.229	1.61	15.231
FCEY	0.573	5.554	2.390	18.279	8.909	2.120	2.750	3.821	44.396

Scenario 4. This table adds an extra row to account for the U32/O26 BAWM (in M lbs). These extra removals are deducted locally from the TCEY. Note that the harvest rates have been adjusted. The areas that had a target harvest of 0.20 in 2009 get the Scenario 4 target harvest rate of 0.215 and the areas that had a target harvest rate of 0.150 get a rate of 0.161.

	2A	2B	2C	3A	3B	4A	4B	4CDE	CW
EBio	4.094	30.382	25.101	130.962	65.723	21.673	19.858	36.207	334.000
HR	0.215	0.215	0.215	0.215	0.161	0.161	0.161	0.161	0.192
TCEY	0.880	6.532	5.397	28.157	10.598	3.495	3.202	5.838	64.099
OR	0.246	0.522	2.63	7.913	0.95	1.131	0.229	1.61	15.231
U32/O26	0.142	0.313	0.337	1.932	1.156	0.447	0.088	0.894	5.309
FCEY	0.492	5.697	2.430	18.312	8.492	1.917	2.885	3.334	43.559

Scenario 5a. This table adds an extra row to account for the U32/O26 BAWM as well as an extra row to account for U26 BAWM (in M lbs). These extra removals are all deducted locally from the TCEY. Note that the harvest rates have been adjusted. The areas that had a target harvest of 0.20 in 2009 get the Scenario 5 target harvest rate of 0.230 and the areas that had a target harvest rate of 0.150 get a rate of 0.173.

	2A	2B	2C	3A	3B	4A	4B	4CDE	CW
EBio	4.094	30.382	25.101	130.962	65.723	21.673	19.858	36.207	334.000
HR	0.230	0.230	0.230	0.230	0.173	0.173	0.173	0.173	0.205
TCEY	0.942	6.988	5.773	30.121	11.337	3.739	3.426	6.246	68.571
OR	0.246	0.522	2.63	7.913	0.95	1.131	0.229	1.61	15.231
U32/O26	0.142	0.313	0.337	1.932	1.156	0.447	0.088	0.894	5.309
U26	0.034	0.021	0.052	1.105	0.477	0.757	0.143	1.519	4.108
FCEY	0.520	6.132	2.754	19.171	8.754	1.404	2.966	2.223	43.923

Scenario 5b. This table adds an extra row to account for the U32/O26 BAWM as well as an extra row to account for U26 BAWM (in M lbs). The U32/O26 removals are deducted locally from the TCEY. Regulatory area-specific deductions for U26 BAWM area based on relative distribution of EBio. Harvest rates are the same as in Scenario 5a.

	2A	2B	2C	3A	3B	4A	4B	4CDE	CW
EBio	4.094	30.382	25.101	130.962	65.723	21.673	19.858	36.207	334.000
HR	0.230	0.230	0.230	0.230	0.173	0.173	0.173	0.173	0.205
TCEY	0.942	6.988	5.773	30.121	11.337	3.739	3.426	6.246	68.571
OR	0.246	0.522	2.63	7.913	0.95	1.131	0.229	1.61	15.231
U32/O26	0.142	0.313	0.337	1.932	1.156	0.447	0.088	0.894	5.309
U26	0.050	0.374	0.309	1.611	0.808	0.267	0.244	0.445	4.108
FCEY	0.503	5.779	2.498	18.665	8.423	1.894	2.864	3.296	43.923

Summary

The results presented above provide the Commission with a basis for evaluating effects of alternatives in the way bycatch and wastage mortality is accounted for in halibut management. For nearly 15 years, bycatch and wastage removals of halibut under 32 inches in size have not been deducted from TCEY, but rather were accounted for in determining a target harvest rate. While staff felt this methodology was appropriate and sufficiently precautionary, there has been increasing dissatisfaction among some constituency with such accounting. This analysis outlines some alternative ways to a more consistent means of accounting for all sources of removals, at all sizes. One scenario allows for direct deduction of U32/O26 BAWM and the other presents a couple of options for further directly deducting U26 BAWM.

The analysis presented here uses a very general harvest policy analysis metric - SBR - to examine a very specific situation. The halibut life history, fishery, and harvest policy are recreated at current conditions and applied to modified conditions to determine an appropriate change in the target harvest rate. The metric that unified the analysis was that any change must have the end result of being as conserving of spawning biomass as the current method.

It is both something of a surprise, as well as a validation, that when the alternative scenario results are applied to the 2010 EBio, the calculated regulatory area FCEYs are all within a few percentage points of each other - with the exception of Scenario 5a and its impact on Area 4. The validation aspect refers to the belief of staff that the methodology of factoring bycatch into the harvest rate calculation as lost recruitment had the effect of lowering harvest rates to what they should be in the absence of direct accounting. Scenario 5a has a larger effect on Area 4 than the other scenarios because local accounting for U26 BAWM is based on a fundamentally different life history model than that of the other Scenarios. It is hoped these results, and ensuing discussion, will help to inform discussion on a consensus method for accounting for the effects of bycatch and wastage.

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Table 1. Comparison of Fishery Constant Exploitation Yield (FCEY) and Slow Up Fast Down (SUFD) adjusted catch and final Catch Limits (CL), in thousands of net pounds, for all IPHC regulatory areas and as a Coastwide (CW) total, 2007-2010. The percentage difference between the FCEY and the last two catch amounts is indicated in the parentheses.

2007				2008			
Area	FCEY	SUFD	CL	Area	FCEY	SUFD	CL
2A	660	1,020	1,340	2A	650	1,000	1,220
		(+55%)	(+103%)			(+54%)	(+88%)
2B	6,220	9,720	11,470	2B	4,650	8,060	9,000
		(+56%)	(+84%)			(+73%)	(+94%)
2C	4,980	7,810	8,510	2C	3,920	6,210	6,210
		(+57%)	(+71%)			(+58%)	(+58%)
3A	27,630	26,010	26,200	3A	22,250	24,220	24,220
		(-6%)	(+-5%)			(+9%)	(+9%)
3B	16,770	12,830	9,220	3B	14,270	10,900	10,900
		(-23%)	(-45%)			-24%)	(-24%)
4A	5,230	3,980	2,890	4A	3,510	3,100	3,100
		(-24%)	(-45%)			(-12%)	(-12%)
4B	2,560	1,970	1,440	4B	2,700	1,860	1,860
		(-23%)	(-44%)			(-31%)	(-31%)
4CDE	3,850	3,650	4,100	4CDE	3,680	3,890	3,890
		(-5%)	(+6%)			(+6%)	(+6%)
CW	**67,900**	**66,990**	**65,170**	**CW**	**55,620**	**59,240**	**60,400**
		(-1%)	**(-4%)**			**(+7%)**	**(+9%)**

2009				2010			
Area	FCEY	SUFD	CL	Area	FCEY	SUFD	CL
2A	500	860	950	2A	573	760	810
		(+72%)	(+90%)			(+33%)	(+41%)
2B	4,920	6,960	7,630	2B	5,554	6,590	7,500
		(+41%)	(+55%)			(+19%)	(+35%)
2C	2,860	4,540	5,020	2C	2,390	3,710	4,400
		(+59%)	(+76%)			(+55%)	(+84%)
3A	20,840	22,530	21,700	3A	18,279	19,990	19,990
		(+8%)	(+4%)			(+9%)	(+9%)
3B	13,200	11,670	10,900	3B	8,909	9,900	9,900
		(-12%)	(-17%)			(+11%)	(+11%)
4A	2,200	2,650	2,550	4A	2,120	2,330	2,330
		(+20%)	(+16%)			(+10%)	(+10%)
4B	2,090	1,940	1,870	4B	2,750	2,160	2,160
		(-7%)	(-11%)			(-21%)	(-21%)
4CDE	1,970	2,930	3,460	4CDE	3,821	3,580	3,580
		(+49%)	(+76%)			(-6%)	(-6%)
CW	**48,580**	**54,080**	**54,080**	**CW**	**44,396**	**49,020**	**50,670**
		(+11%)	**(+11%)**			**(+10%)**	**(+14%)**

Table 2. Summary of total removals, averaged for 2007 to 2009, in millions of net pounds, by fishery and size category. "CW" is coastwide (i.e., the sum of all regulatory areas. Column labels are used to describe summaries in Tables 3-5.

	A	B	C	D	E	F	G	H	I	
	Commercial	Sport	Subsistence	Bycatch (U26)	Bycatch (26-32)	Bycatch (O32)	Wastage (U26)	Wastage (26-32)	Wastage (O32)	Total
2A	0.659	0.453	0.031	0.036	0.136	0.155	0.000	0.014	0.000	1.485
2B	8.064	1.390	0.369	0.016	0.087	0.108	0.011	0.300	0.019	10.362
2C	6.543	2.893	0.522	0.038	0.089	0.215	0.013	0.233	0.017	10.563
3A	24.240	5.481	0.363	1.021	0.848	1.031	0.049	0.938	0.051	34.022
3B	10.260	0.021	0.045	0.390	0.445	0.469	0.070	0.556	0.013	12.270
4A	2.785	0.042	0.019	0.681	0.304	0.565	0.021	0.114	0.009	4.540
4B	1.587	0.000	0.000	0.144	0.078	0.214	0.002	0.015	0.003	2.043
4CDE	3.682	0.000	0.081	1.624	0.888	1.627	0.005	0.074	0.010	7.992
CW	57.820	10.280	1.430	3.949	2.876	4.384	0.171	2.244	0.123	83.276

Table 3. Total removals by percent for the three summed fisheries for Scenario 3. For Scenario 3, the Commercial category includes Columns A and I from Table 2, the Sport/Subsistence category includes Columns B and C, the Bycatch category is Column F.

	Commercial	Sport/Subsistence	Bycatch
2A	51%	37%	12%
2B	81%	18%	1%
2C	64%	34%	2%
3A	78%	19%	3%
3B	95%	1%	4%
4A	82%	2%	17%
4B	88%	0%	12%
4CDE	68%	2%	30%
CW	78%	16%	6%

Table 4. Total removals by percent for the three summed fisheries for Scenario 4. For Scenario 4, the Commercial category includes Columns A and I from Table 2, the Sport/Subsistence category includes Columns B and C, the Bycatch category includes Columns E, F, and H.

	Commercial	Sport/Subsistence	Bycatch
2A	46%	33%	21%
2B	78%	17%	5%
2C	62%	32%	5%
3A	74%	18%	9%
3B	87%	1%	12%
4A	73%	2%	26%
4B	84%	0%	16%
4CDE	58%	1%	41%
CW	73%	15%	12%

Table 5. Total removals by percent for the three summed fisheries for Scenario 5. For Scenario 4, the Commercial category includes Columns A and I from Table 2, the Sport/Subsistence category includes Columns B and C, the Bycatch category includes Columns D, E, F, G, and H.

	Commercial	Sport/Subsistence	Bycatch
2A	44%	33%	23%
2B	78%	17%	5%
2C	62%	32%	6%
3A	71%	17%	11%
3B	84%	1%	16%
4A	62%	1%	37%
4B	78%	0%	22%
4CDE	46%	1%	53%
CW	70%	14%	16%

Table 6. Summary of harvest rates and resultant catches (in millions of pounds) at which SBR is reduced to 32% of unfished under each of the five scenarios. Note that what constitutes "catch" differs markedly both among the scenarios, and within the O32 Bycatch + U32 BAWM category (see text for details).

	Scenario				
	1	2	3	4	5
Harvest rate	**0.295**	**0.250**	**0.200**	**0.215**	**0.230**
Commercial + O32 Wastage	112.7	82.4	59.6	59.7	62.1
Sport + Subsistence	---	---	12.2	12.3	12.4
O32 Bycatch + U32 BAWM	---	---	4.6	9.8	14.2
Total avg. catch	**112.7**	**82.4**	**76.4**	**81.8**	**88.7**

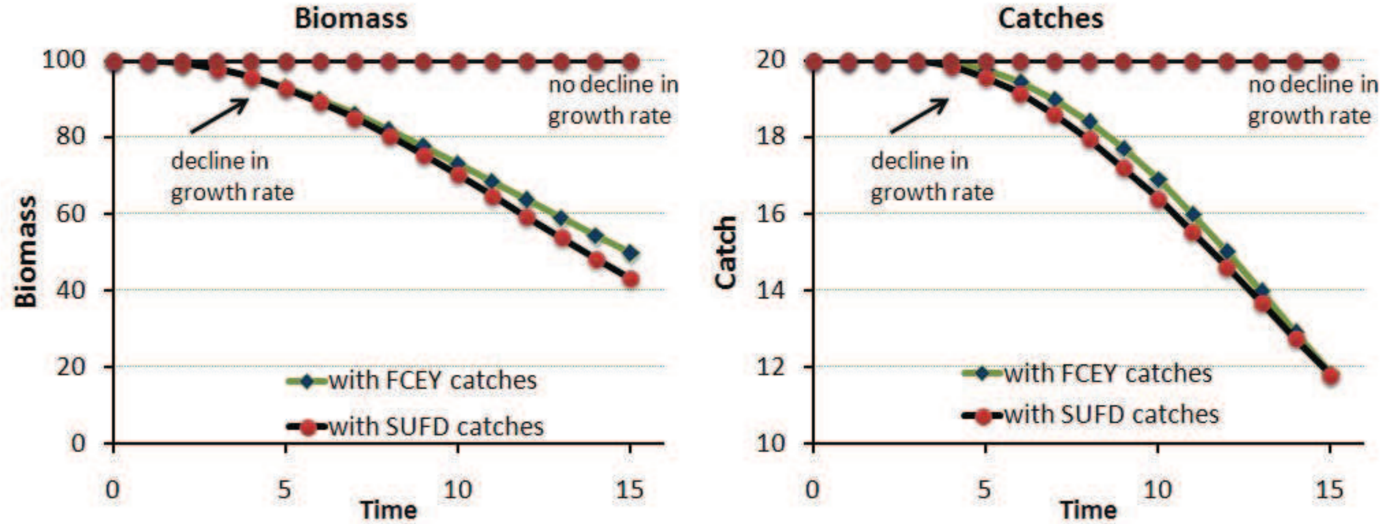

Figure 1a. Performance of SUFD policy under conditions of declining growth rates. The scenario with FCEY catches illustrates what catches and biomass would have been if no SUFD adjustment had been applied.

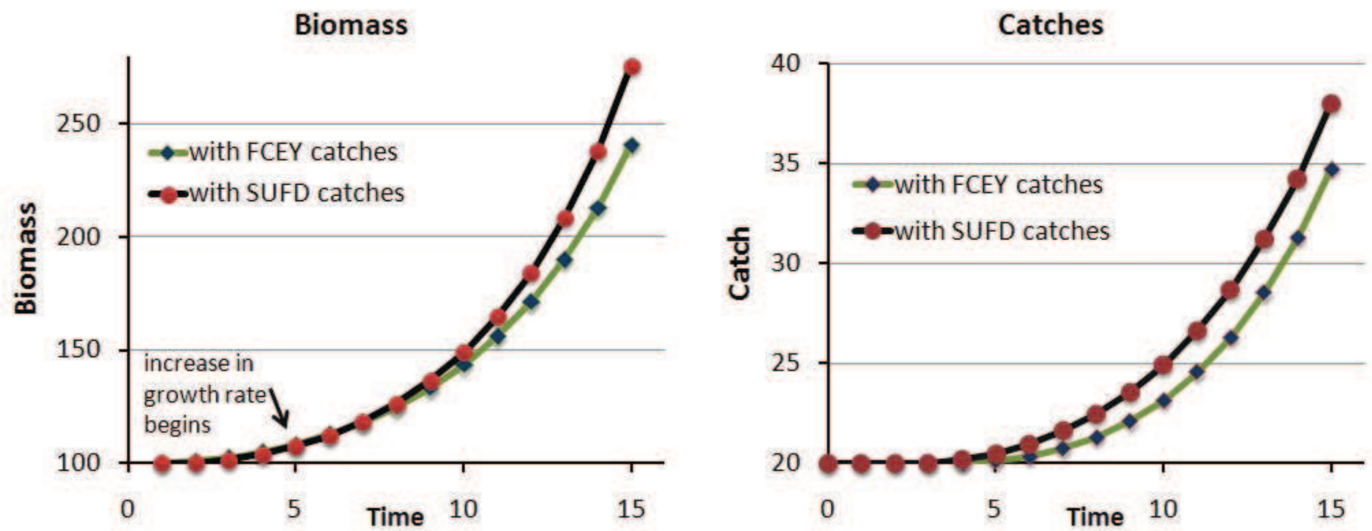

Figure 1b. Same as Figure 1a but starting from a higher than target harvest rate.

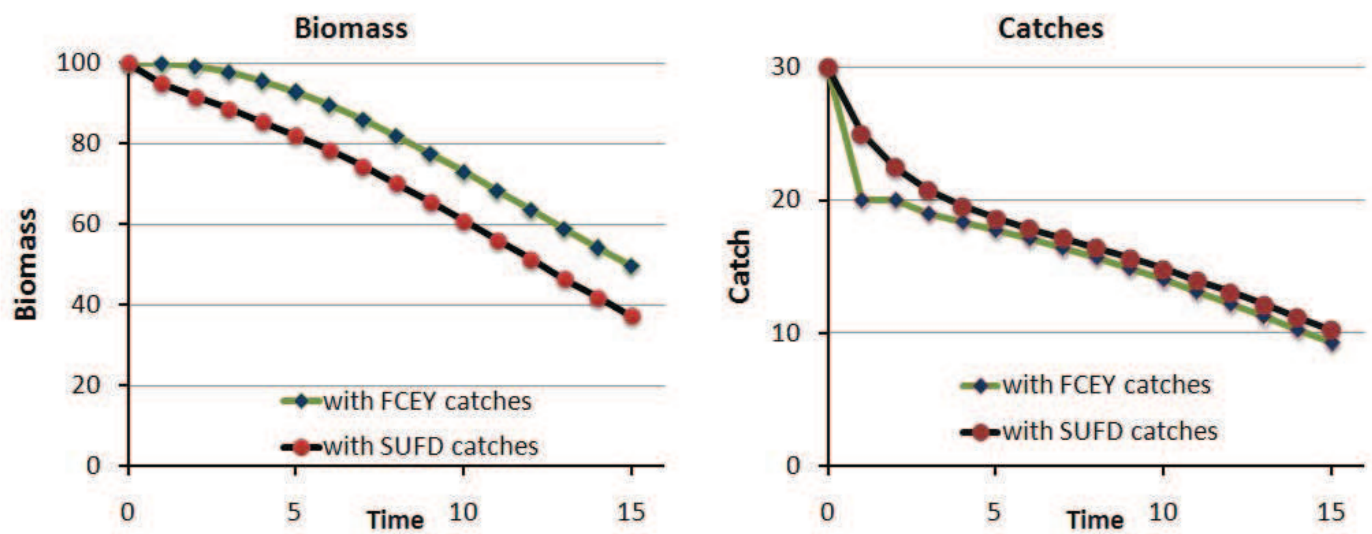

Figure 1c. Same as 1a, but under conditions of increasing growth rates

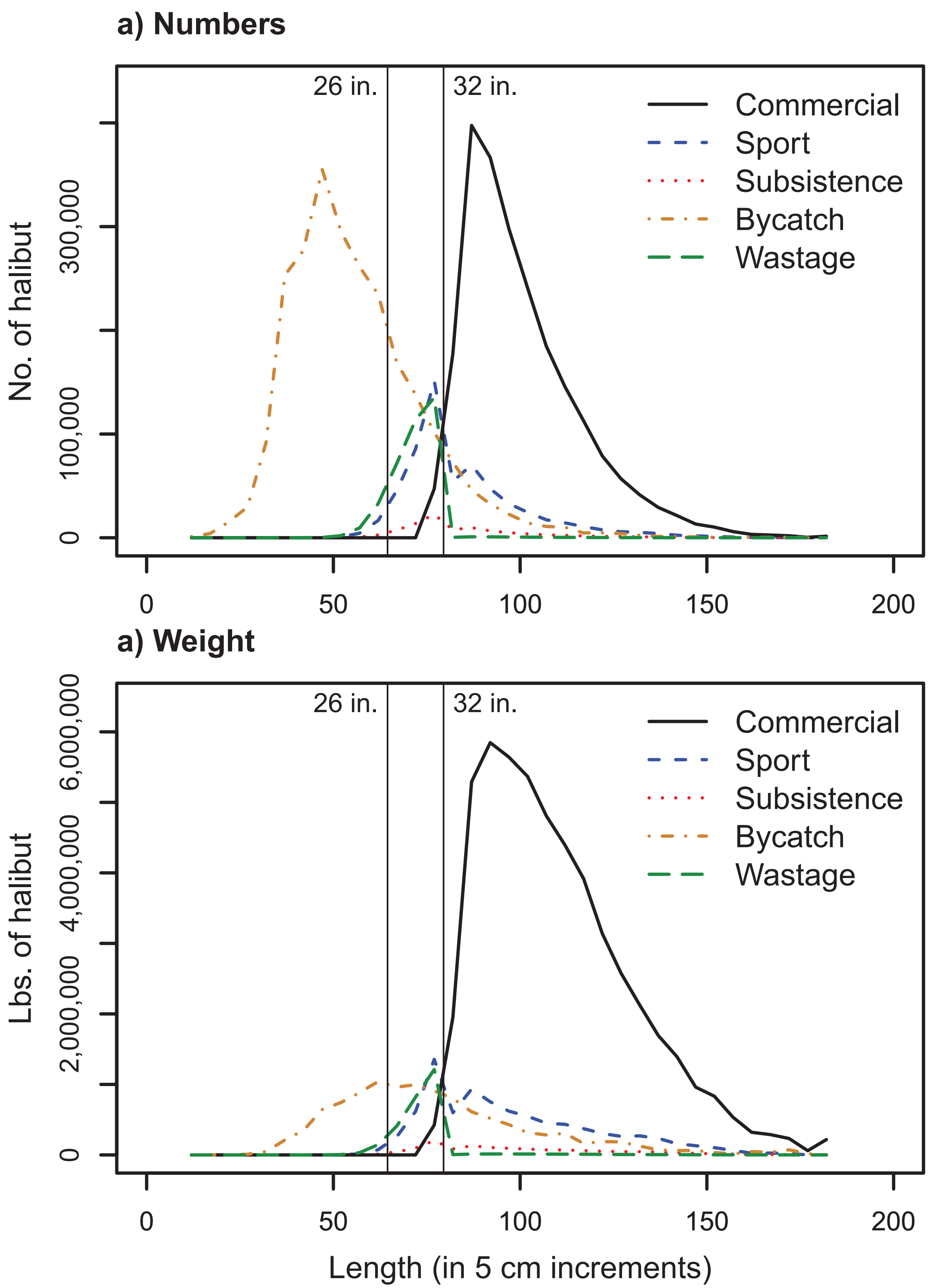

Figure 2. Coastwide size distributions of removals by fishery

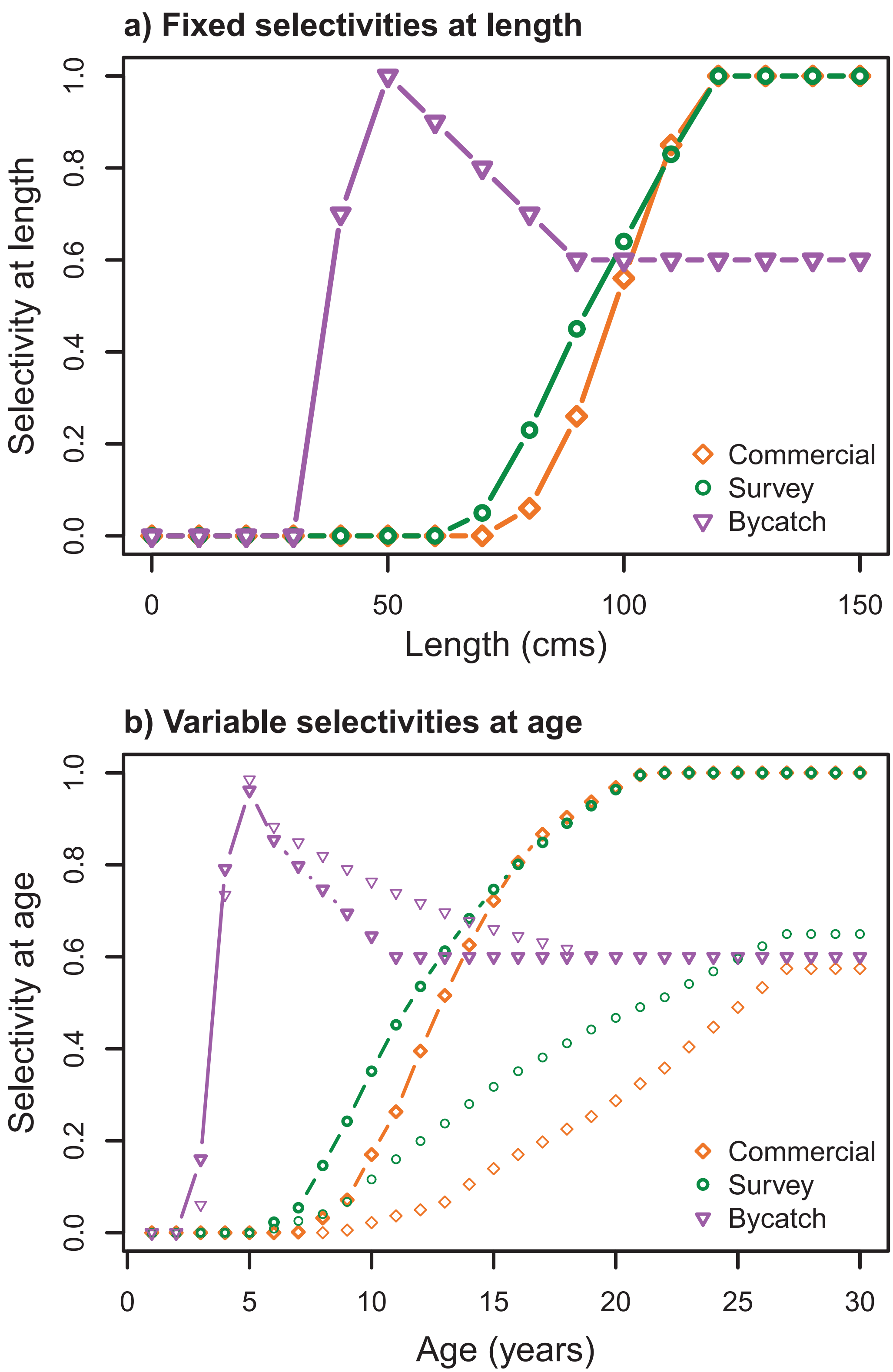

Figure 3. Selectivities used for harvest policy reanalysis. Upper plot shows fixed selectivities at length. The lower plot shows the resulting selectivities at age given the size at age data for 2007-2009.

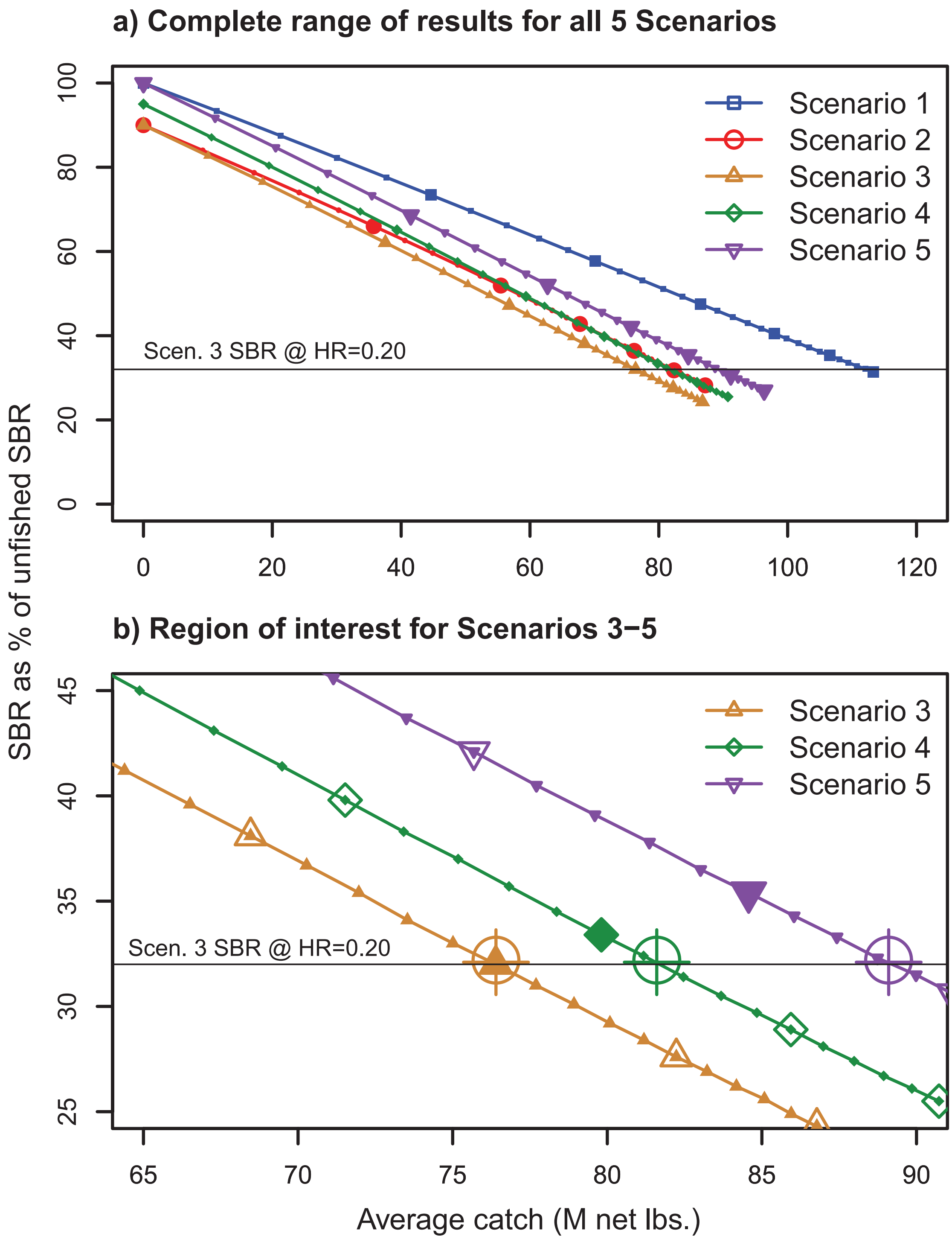

Figure 4. Results of Spawning Biomass per Recruit (SBR) analysis. See text for definition of Scenarios. Panel a shows the Average Catch vs. SBR curves as a function of increasing harvest rate. The upper left point of each curve is a harvest rate of 0.0; each dot down the curve represents an increase of 0.01; the large dots are in multiples of 0.05 and the large shaded dot indicates a harvest rate of 0.20. The horizontal line is the SBR for Scenario 3 at harvest rate of 0.20. Panel b contains the same data as Panel a but is zoomed into the region of interest without the first two Scenarios plotted. The bullseyes show the harvest rate that reduces SBR to the same level as a harvest rate of 0.20 in Scenario 3.